Relevant momentum components of gluons for confinement and chiral symmetry breaking

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A. Y. and H. Suganuma, PRL 101, 241601 (2008),
PRD 79, 054504 (2009),
PRD 81, 014506 (2010).

A. Y., PLB 688, 345 (2010),
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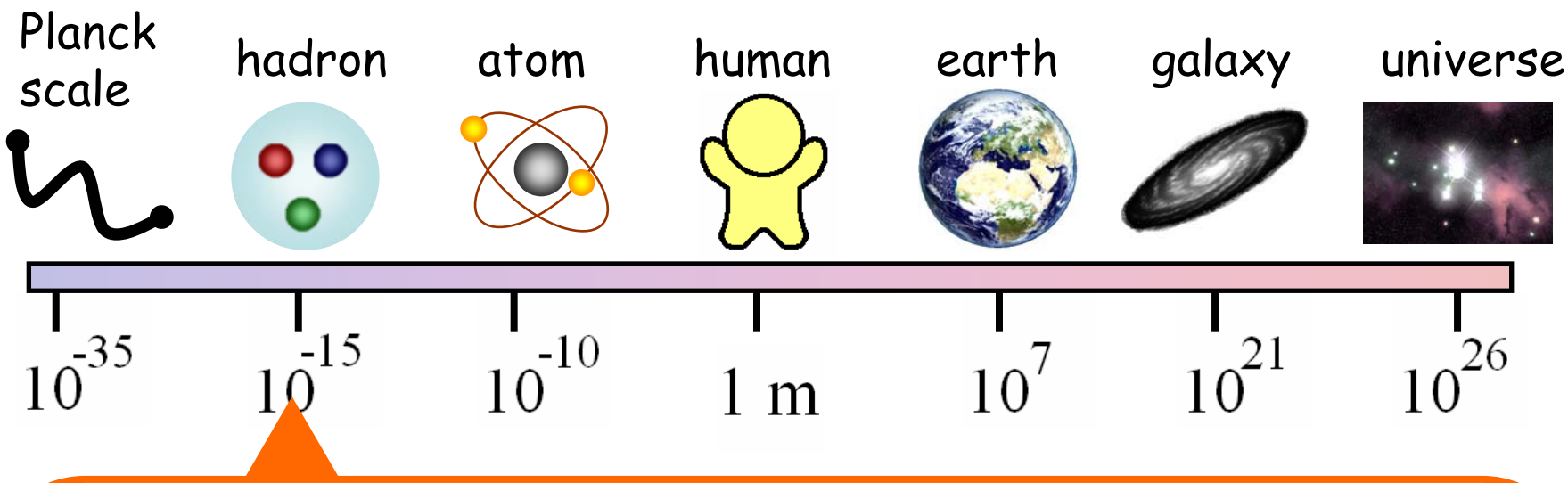
Introduction



QCD running coupling constant : $\alpha_s(p^2)$

high energy
weak coupling
perturbative

⟺

low energy
strong coupling
non-perturbative

The behavior of a QCD phenomenon depends on the energy scale.

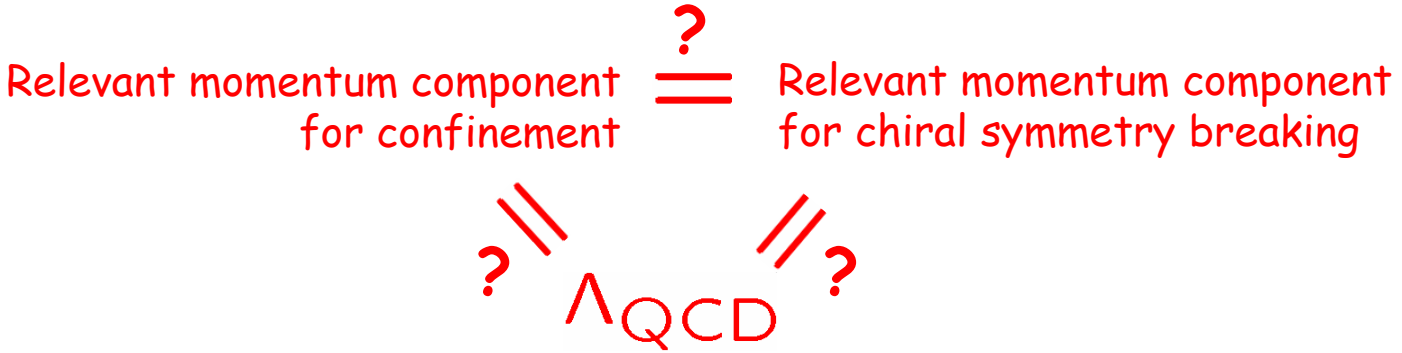
Question:

"Which momentum component of the gluon field induces a QCD phenomenon?"

We analyzed such **"relevant momentum components"** for

- **color confinement**
- **spontaneous chiral symmetry breaking**

in quenched SU(3) lattice QCD.



Formalism in Lattice QCD

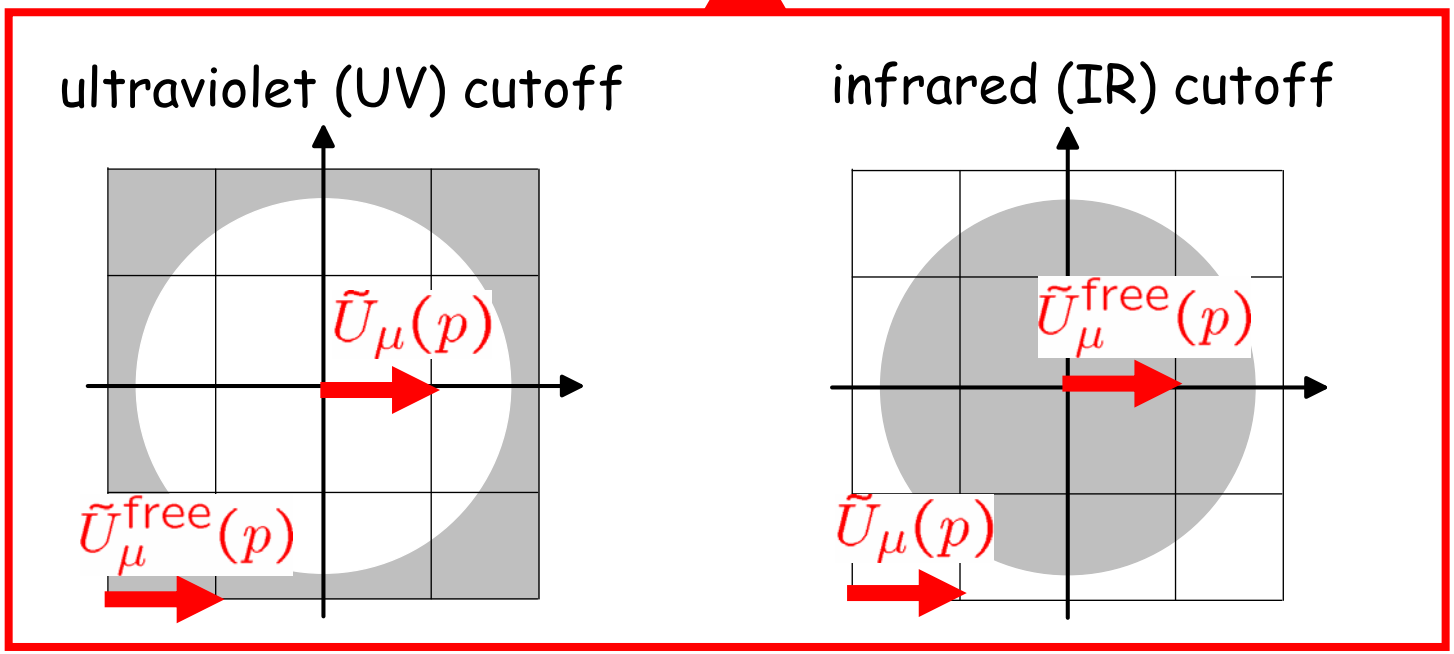
coordinate space

gauge fixed $U_\mu(x)$ → $U^{\wedge}_\mu(x)$ ⇨ $\langle \hat{O}[U^{\wedge}] \rangle$

Fourier tr. ⇩ ⇧ Fourier tr.

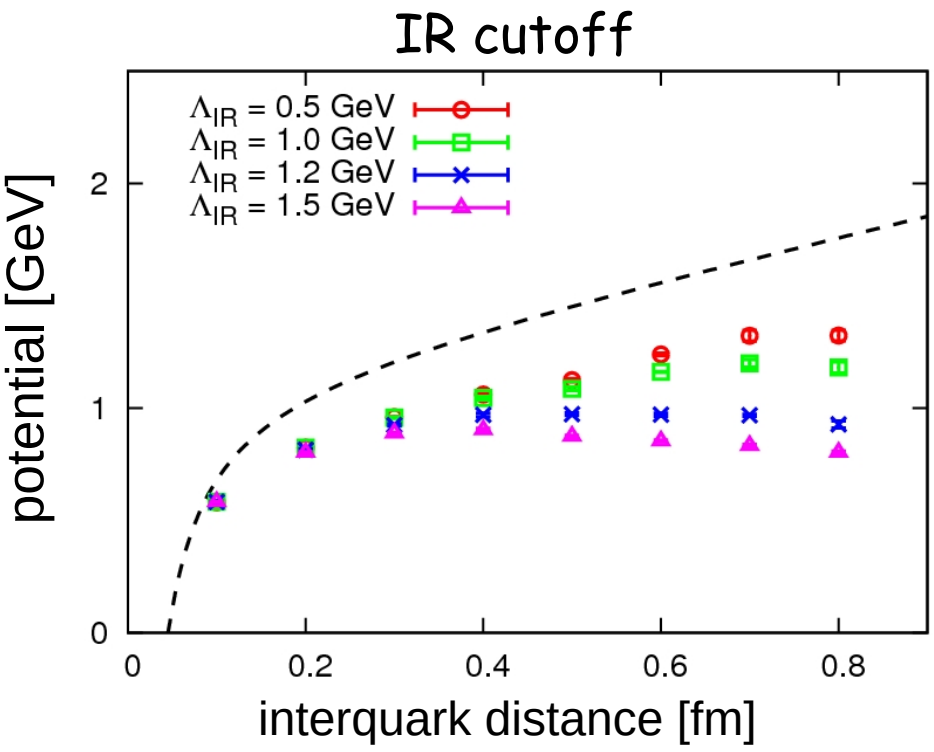
momentum space

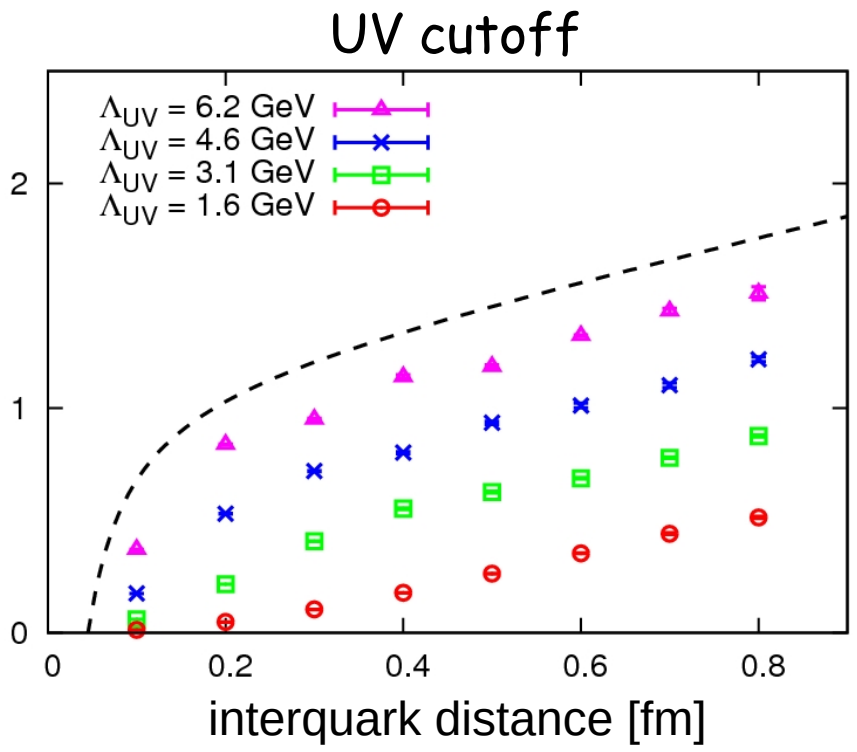
$\tilde{U}_\mu(p)$ ⇨ "cut" $\tilde{U}^{\wedge}_\mu(p)$



Numerical Results

Quark-antiquark potential

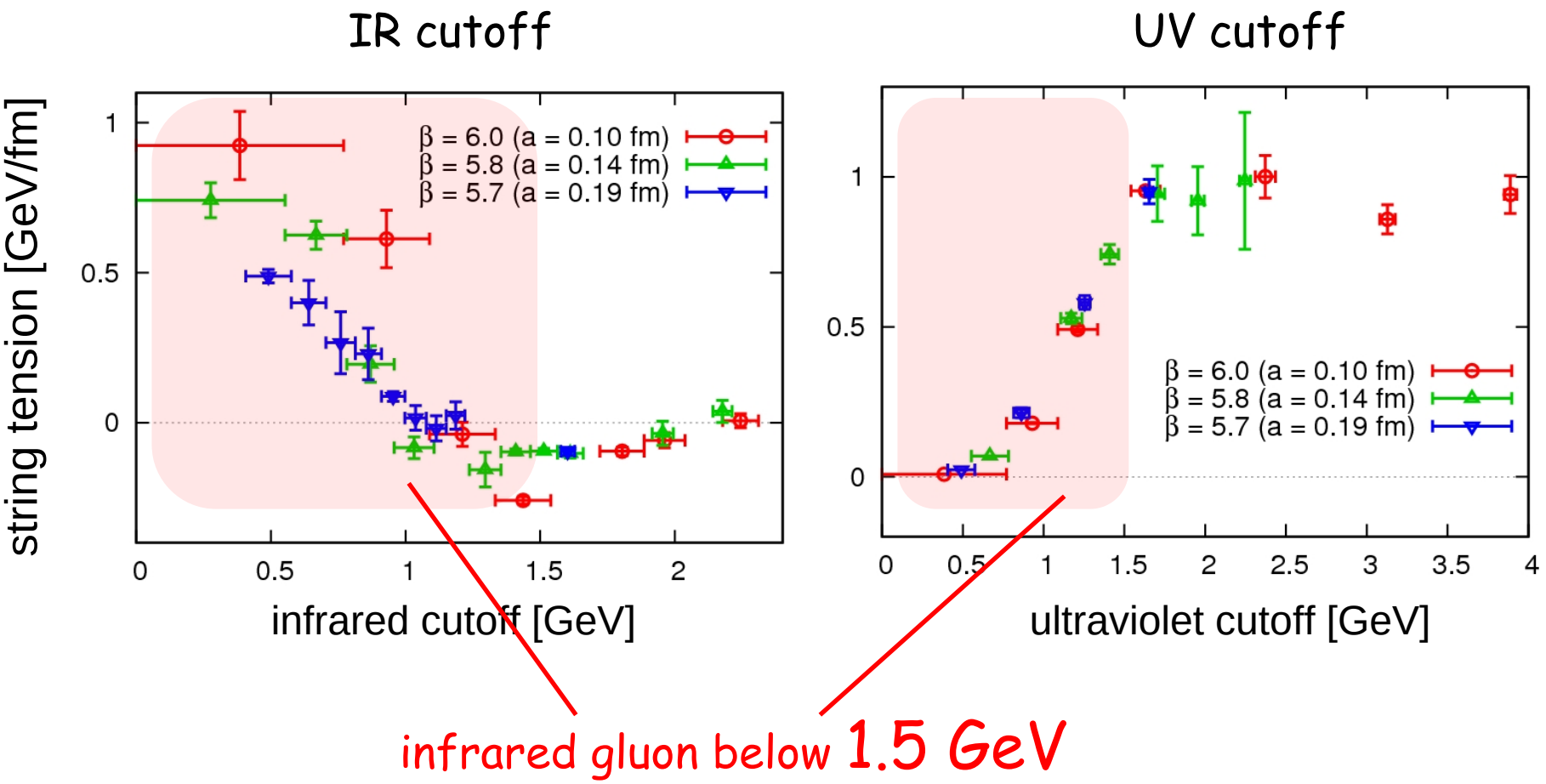




confinement potential (IR) disappears

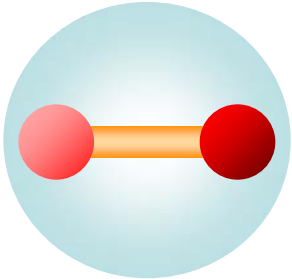
Coulomb potential (UV) disappears

String tension

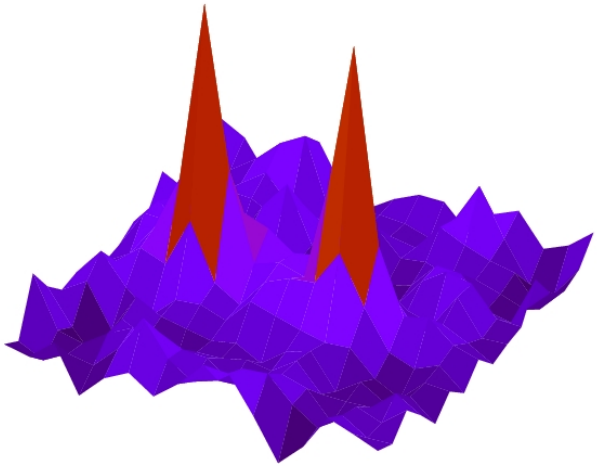


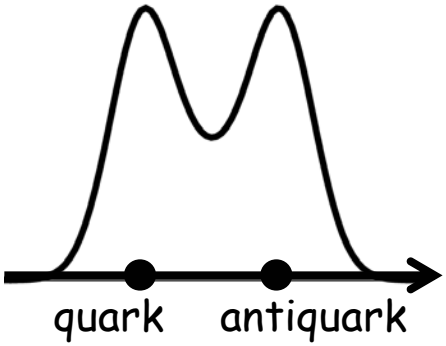
Color flux tube

"flux tube" or "string" between static quarks

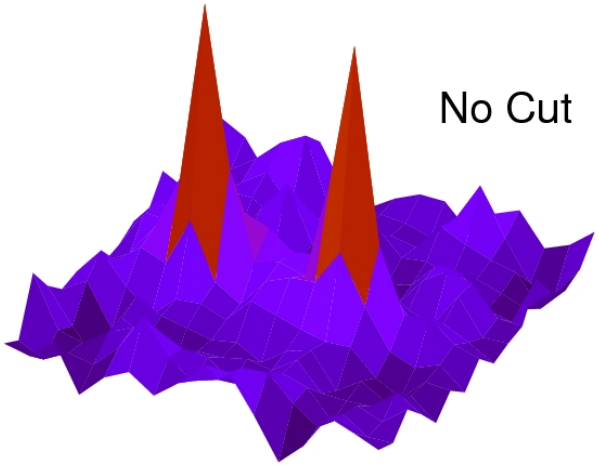


Spatial distribution of action density around the Wilson loop:

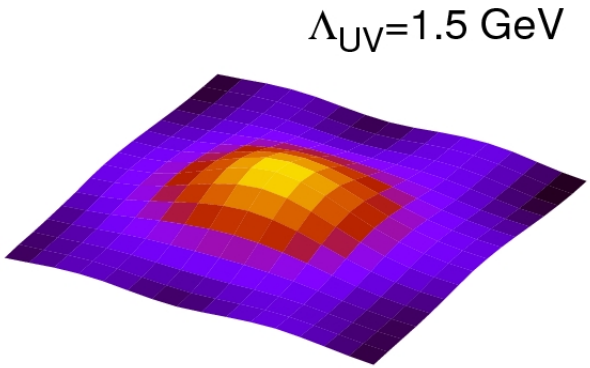


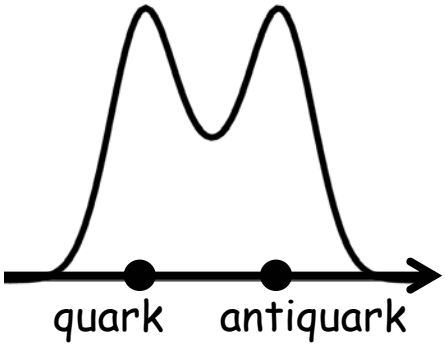


Color flux tube



UV cutoff





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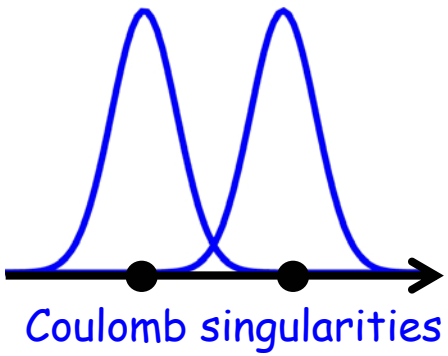

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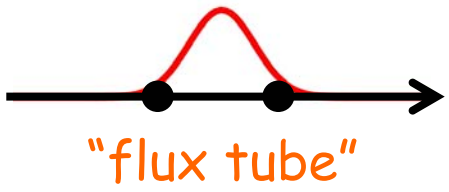
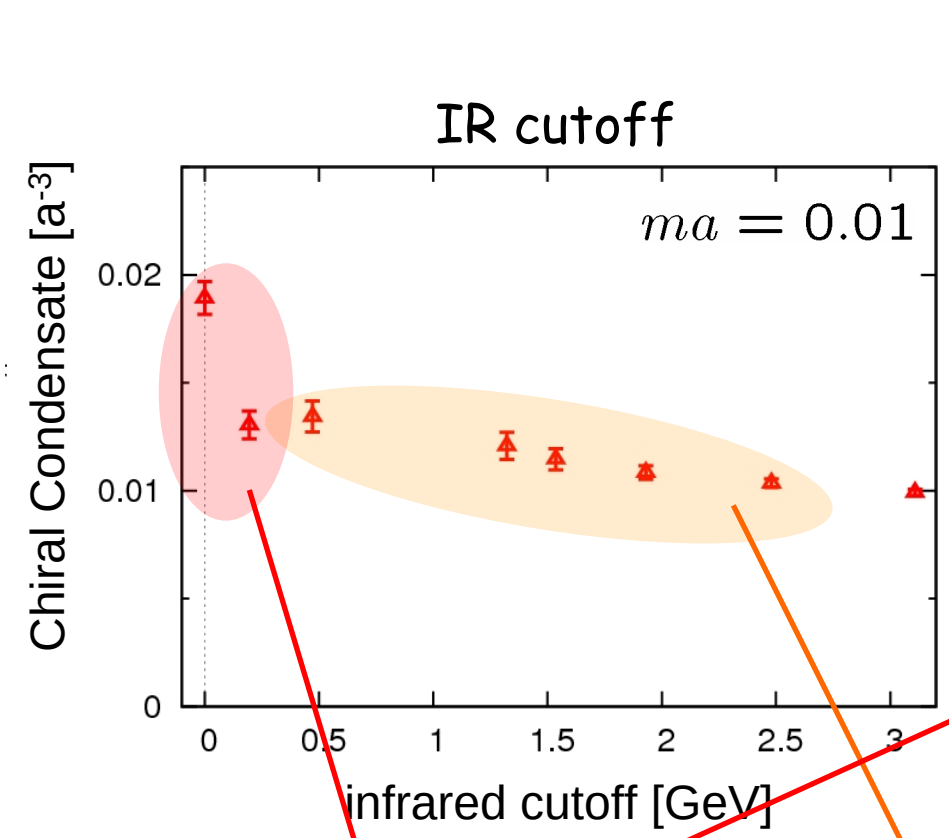
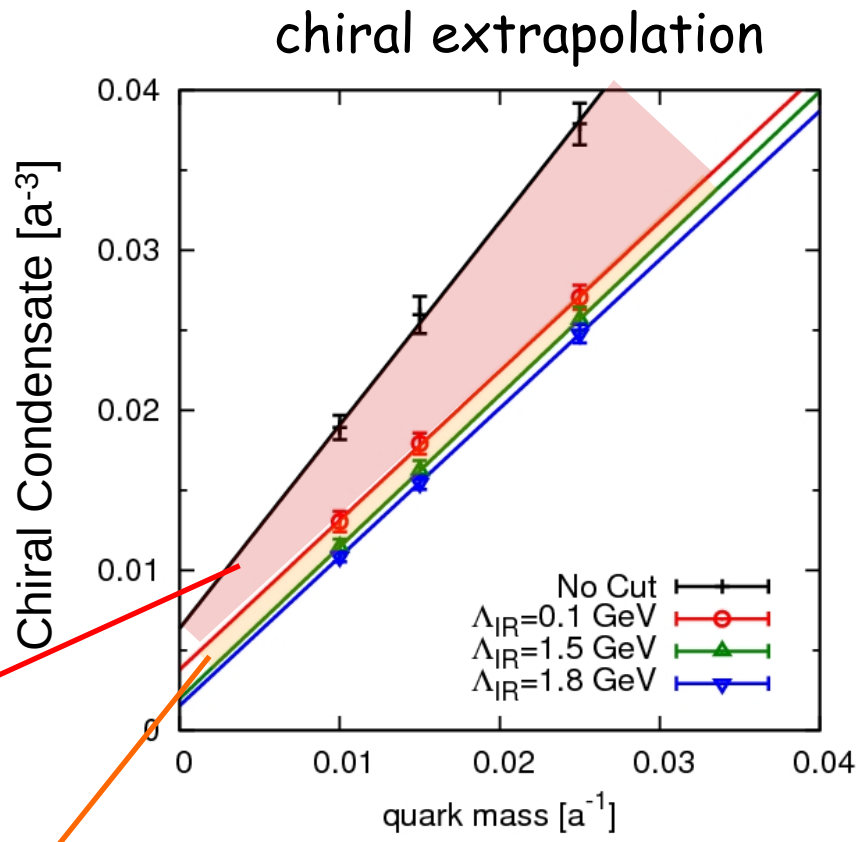


Chiral condensate





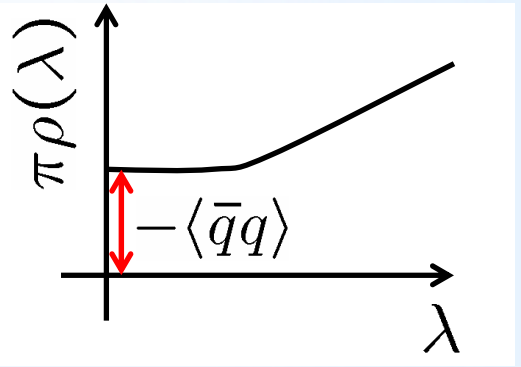
deep-infrared gluon

intermediate-infrared gluon

Chiral condensate

Banks-Casher relation [T.Banks, A.Casher (1980)] :

$$-\langle \bar{q}q \rangle = \pi\rho(0)$$



$\rho(\lambda)$: spectral density of the Dirac operator

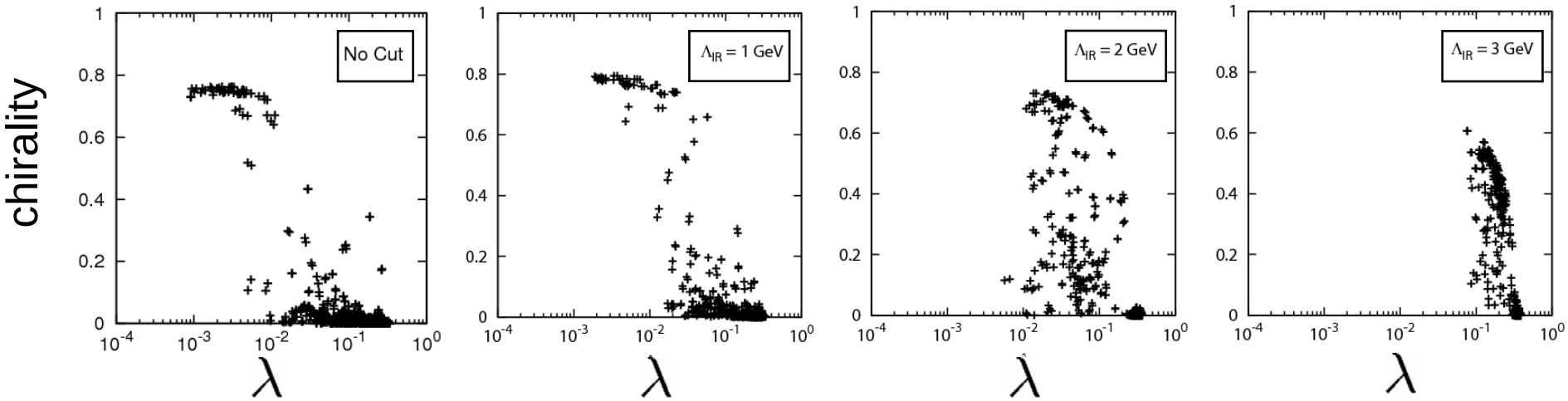
chiral condensate ⟷ Dirac eigenvalue of quarks

momentum component of gluons

Dirac spectrum

The Dirac eigenvalue spectrum:

$$\gamma_\mu D_\mu \psi = i\lambda\psi$$



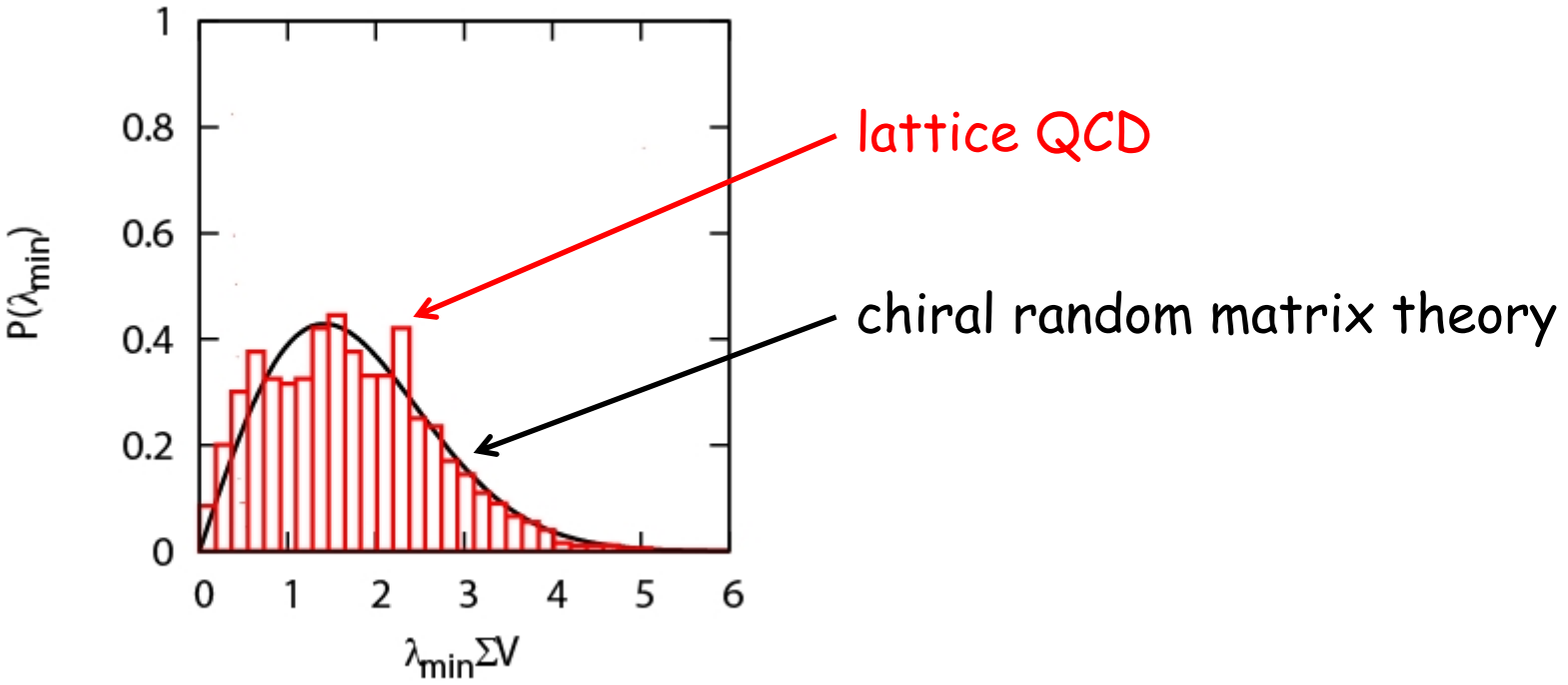
Gradually changed

Dirac spectrum

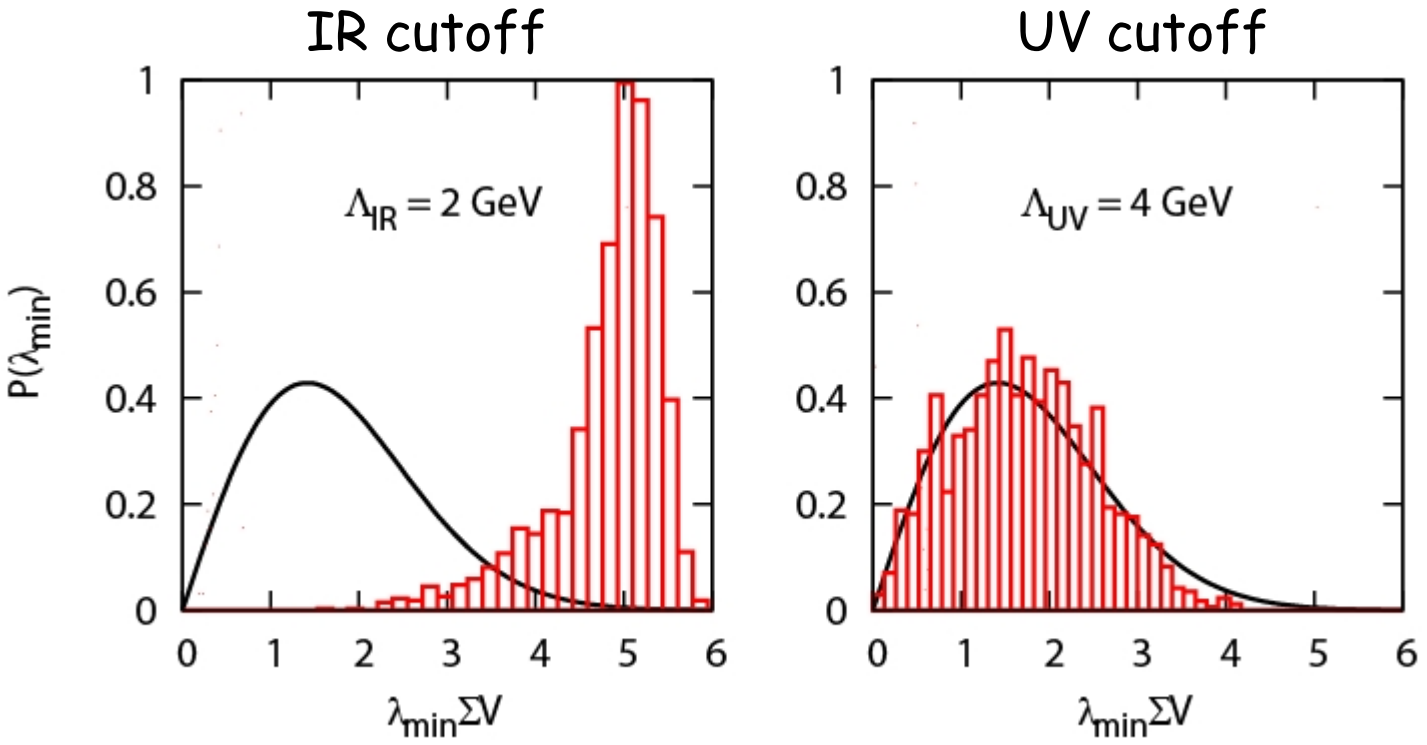
The low-lying Dirac spectrum is described by **chiral random matrix theory**.

The gluon field is "random".

The smallest Dirac eigenvalue (Q=0 sector):



Dirac spectrum



Drastically changed

Not changed

Summary

- We formulated a framework to determine the relevant momentum components of gluons for QCD phenomena.
- We analyzed confinement and chiral symmetry breaking in quenched lattice QCD at the Landau gauge.
- The infrared gluon below 1.5 GeV contributes to confinement.
- The broad momentum region of gluons contributes to chiral symmetry breaking.